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EcoQuad - Device for Sustainable Transport by Hybridization of Electricity and Photovoltaic Solar Energy

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***Abstract*— *Over the past decades, global warming has been widely discussed around the world. Along with the phenomenon itself, it is also discussed the fact that one of its main causes is the emission of polluting gases into the atmosphere, which in turn are produced by cars and other means of transportation. About the situation, it has become common for environmental issues to be explored and the tendency of large automobile companies to start the production of vehicles that do not use fossil fuels, in addition to seeking solutions also related to the format of these vehicles. However, such solutions have several flaws, because they are rarely accessible to the population, in addition to using different energy sources that are still harmful to the environment. Another obstacle that can be noted is the lack of interest of the population in other types of vehicles that are not common or convenient and that require some adaptability. New solutions must be created so that economic, social and ecological aspects are met. In this way, the development and execution of a personal car called EcoQuad is presented, whose purpose has an educational and political character, thus seeking to promote a new style of production based on the hybridization of electric and solar photovoltaic energy. As a scientific character, the development of this project aims to prove the ecological and efficient aspects that can be achieved together through the hybrid energy system described. Because it is a hybrid vehicle, powered by batteries and solar panels that work together, the cost benefit is superior to ordinary vehicles, because with the correct distribution of energy used from the battery bank and solar modules, vehicle maintenance will be more affordable and less frequent. For such an experiment to be possible to be executed, it is concluded the need to expand the technological nationalization, which would make the project commercially viable. The project was guided by teachers and executed by high school students from Colégio Puríssimo Coração de Maria, ICM Education Network, and was presented at the Brazilian Science and Engineering Fair*

(FEBRACE) in 2023, winning 1st place in the Engineering category and 4th place overall in the largest Science and Engineering Fair in Latin America.

I. INTRODUCTION

Urban pollution has always been a major problem in industrialized and developing countries. In recent times, the world has experienced a high concentration of air pollutants in urban regions. Linked to this, the climate phenomenon "global warming"

has become increasingly commented on in current times. It is known that the main cause of such an event is the growing emission of polluting gases, which result from the use of automobiles and other types of transportation that are developed based on the same principle of energy generation. In addition, it is understood that Brazil is experiencing a serious crisis in its economy, especially in the increase in fuel prices, as a result of the return of global economic growth and the consequent search for commodities.

From this principle it has become common to disseminate ideals that encourage the production of environmentally friendly transportation devices, both in the materials that constitute these products and in the forms of fuels used. However, these "solutions" become impractical in the current Brazilian market because the number of people capable of owning such technology does not represent the majority of the population. Linked to this, locomotion alternatives such as walking, bicycles or electric motorcycles have shown not to meet the needs and expectations of the population, culminating in the same environmentally harmful transportation mentioned above.

At the 26th UN Climate Conference, COP 26, they turned to transportation. One of the agreements reached was signed by 24 countries and a group of car manufacturers, who pledged to end the era of fossil fuel vehicles by 2040 "or earlier".

That said, new solutions need to be developed in order to meet the need for a sustainable energy source, but that fits the conventional transportation model and already appreciated by the population, so that there is a concrete adherence to the new style of locomotion.

It is understood the need for an affordable and realistic introduction of technological and sustainable evolution for a country like Brazil, in order to achieve the proposed metrics of gas emission reduction from a fully replicable technology.

II. OBJECTIVE AND PROBLEM QUESTION

Question Problem

Currently, the transportation sector uses more than 50% of petroleum products and more than 40% of all fossil energy consumed in the country. It is therefore one of the sectors that can contribute most to reducing greenhouse gas emissions and other pollutants (BARAT, 2007).

According to a study by the Institute of Applied Economic Research (IPEA), about 20% of users of public roads, especially in large cities, are responsible for occupying 80% of them. This problem is caused by several factors, among which the main ones are the following: historically the country has prioritized private transport with incentives to automakers and consumers to acquire their cars, poor conditions of use of most means of public transport such as buses and trains and the poor planning of cities regarding public roads and long distances between homes and workplaces.

According to this same IPEA study, private cars, cabs and motorcycles obtain subsidies of around R$ 20.0 billion each year, corresponding to 86.0% of all subsidies given to the transportation system by the three spheres of government. On the other hand, public transportation has annual subsidies of around R$ 3.0 billion, corresponding to 14.0%.

Since its implementation in 1986, the Program for the Control of Air Pollution from Motor Vehicles (PROCONVE) has reduced the emission of pollutants from new vehicles by about 97%, through the progressive limitation of pollutant emissions (VASCONCELLOS, 2000), through the introduction of technologies such as catalytic converters, electronic fuel injection and improvements in automotive fuels.

However, problems such as pollution, degradation, gas emissionsand mass consumption are also a reflection of development and, although they are the topic of discussions and protests, they do not generate significant commotion and repercussion on the part of the population. As a result, these problems are still present and are getting worse every day.

The search for alternatives that really work at all social levels is scarce, when in fact, it should be the way out to improve the world. Motivation comes from each individual and individual involvement is needed to recover decades of waste and mistreatment of the environment. It is also necessary, more than the acceptance by countries and economic powers in treaties and protocols, cheap, viable projects that are within everyone's reach, to start this new model and thus represent the collective interest of the population, signaling to large companies to completely change their production styles to be based mainly on sustainability.

Objective

The main objective of this work is to prove the possibility of a new style of production in the automobile market, in order to reduce the emission of carbon dioxide and cheapen the cost of supply, since electricity is generally cheaper than fossil fuels. Thus, the development and execution of a solar-powered electric car for personal use is presented, whose objective is educational and political, thus seeking to promote the benefits of electric vehicle technology and promote a new style of production based on the hybridization of electric and solar photovoltaic energy.

It is necessary to emphasize that this vehicle was produced with the premise of having an optimal cost benefit, since the correct use of the battery bank and the proper use of the charger, autonomy will be the key point of this article. Therefore, many of the choices made regarding the materials used were made based mainly on the cost and efficiency presented. Some of these parts were already in possession, but in disuse, so even though they did not demonstrate the best cost-benefit and the most correct models to be used, they were adopted in the project.

The problem of cars overheating during prolonged disuse in open spaces such as parking lots is also understood. In the open, it is estimated that the internal temperature of a car can reach 70°C. Moreover, with the increasing rise in global temperature due to high gas emissions, this figure is only set to rise. In this way, it is intended to use these consequences of human exploitation in favor of reducing pollutants in the environment. The electric car is developed with the premise of standing in an open environment while its user works, in order to use all the energy from the sun's rays that would be wasted in just heat in the car's structure, so that it also feeds the battery used on the way from home to the workplace.

The project was developed based on a common lifestyle, in which a commute to work would be made, with the battery being charged during the night. During working hours, the car will be at rest and the energy used during the morning commute will be replenished through the solar plates, which will reach maximum efficiency during midday, as will be proven in this article.

III. DESCRIPTION OF MATERIALS AND METHODS

Structure

For the support and general structuring of the car, metal bars such as metalon (20mm x 20mm) and small iron plates (scraps) were used. The entire structure was welded and some structures were properly screwed or fitted. Since metalon is a high cost-benefit material if we take into account its high toughness, its price, and its lightness, it is one of the best applicability materials for this project. In addition, if we compare it with other materials, such as aeronautical aluminum, the price to weld it is considerably lower than the others.

Therefore, it should be remembered that this project has a demonstrative character, in which it aims to suggest a low-cost car model with reasonable performance over short distances.

The seats were bolted directly to the EcoQuad tubes, and metalon structures were developed at a lower level than the seats to house the batteries and controller.

Above the passengers, four metal bars were used to support the solar panels, which will be discussed later in this article. The latter were fixed by screws in the opposite directions of length, i.e., in the front and rear of the way they were positioned. Due to their large size, both plates served as the roof of the car, with the absence of any metal plate or material that would serve as support for the pair.

As a base for the car structure, two identical bicycles that were in disuse were used, connected through 3 hollow steel bars, with a diameter of 1 inch. Aiming at greater stability and durability, bars with a larger diameter were chosen at the bottom of the vehicle, considering that the weight forces of the passengers, the battery, the solar panels and the upper structure would be directed between the bicycles, in addition to pressing the 4 tires that make up the car.

In addition, the EcoQuad structure was designed to equally distribute the total weight supported on the three lower bars, with a substantial focus on the third bar, located at the rear, which has greater strength potential compared to the others due to its interconnection with both bike suspensions.

Regarding the tires, they are original of the bikes themselves and it is estimated that each one supports the weight of 100Kg each, filled with compressed air and with approximately 35 lbs of pressure. Since the force would be distributed among the four tires, the entire structure and its contents could not exceed 400 kg. Below is the table indicating the objects and their respective mass values. The following information has been approximated always above its real value for a more simplified visualization.

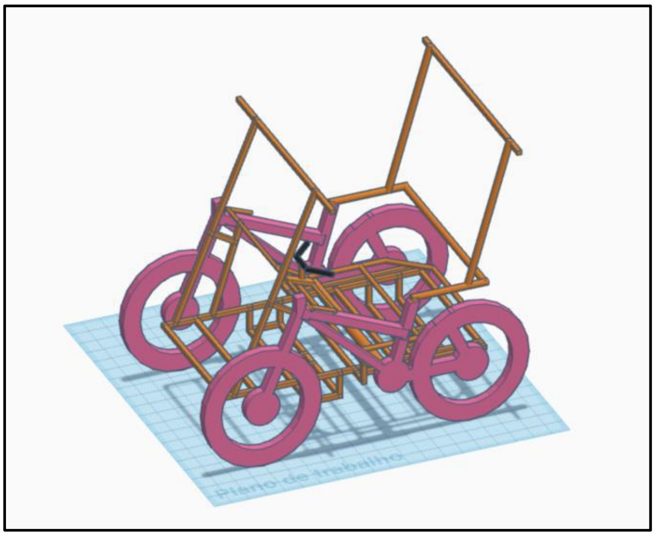

Fig.1 - Ecoquad Structure, Developed with Tinkercad

Table 1 - Objects Supported by Bicycles

Device	Quantity		Mass (kg)
Solar plate	2 pcs.		24 Kg
Battery	3 pcs.		54 Kg
Bicycle	2 pcs.		15 Kg
Engine	1 pcs.		5 Kg
Controller	1 pcs.		1 Kg
Aluminum sheets	0,42 m²		1 Kg
Metal bars	25 m		30 Kg
Occupants	2 pcs.		170 Kg
	Total Mass		**300 kg**

Battery

For the choice of battery, it was established to use the VRLA Deep Cycle Gel system, as it is more common, there is no risk of explosion, widely used in the market and relatively cheap, if compared to more modern batteries. Although the lead acid battery closely resembles a common automotive battery, the latter is not recommended for the use of photovoltaic systems. This is due to the need for prolonged electric current from the photovoltaic system. The automotive battery is designed to deliver an intense electric current for a short period, in order to be favorable for the initial torque in a car, for example. Because of this characteristic, automotive batteries are quickly discharged, and can only undergo a small level of discharge - compared to the stationary lead acid battery - in order to extend their useful life (VILLALVA, 2012). These factors make it impractical to use them in systems that require a continuous and moderate load of energy for a considerable period of time, such as the vehicle discussed in this article.

The autonomy of the prototype is directly proportional to the amount of charge accumulated by the batteries and, therefore, we opted for three imported models of 12 Volts and 70Ah each, of the Freedom brand, which will be installed on the support and connected in series with each other with the intention of extracting 36 Volts from the set. We must remember that the specifications of the engine designated for this project are: 36 Volts and 750 Watts.

The batteries were positioned on metalon supports, specifically designed for this type of use, below the level of the seats.

During the operation of this car, it is necessary to monitor the charge of the batteries, as the depth of discharge will be proportional to the autonomy of the prototype. This monitoring will be performed through a manually developed voltmeter. as will be described throughout this article, a charge controller will be used for intelligent management of battery recharging by solar photovoltaic energy. Although the controller has an auto-off function if the battery bank voltage decreases and the health of the set is impaired, this action would be done without any warning and could cause serious accidents if the car is currently being used. Because of this, a system was developed using Arduino, capable of emitting an alert sound, which intensifies as the voltage continues to decrease.

Controller

Photovoltaic systems with batteries must necessarily employ a charge controller or regulator. The charge controller is the device that makes the correct connection between the photovoltaic panel and the battery, preventing the battery from being overcharged or discharged excessively (VILLALVA, 2012).

Most controllers recharge the battery to maintain a healthy charge profile, thereby increasing battery life and maximizing utilization. More improved controllers also have maximum power point tracking (MPPT) of the PV modules, which enables increased system efficiency.

The controller used in EcoQuad is from the ***Powmr*** brand, directed to solar load and with MPPT function, presenting a maximum current of 60A and voltages of 12, 24, 36 and 48 Volts.

Maximum power point tracking (MPPT) contributes in particular to the charging of batteries using solar energy. Assuming that the car is parked in the open air but the insolation is very low, causing a voltage of 20 Volts, for example, it would not be possible to charge the 36 Volt voltage battery bank. At this point, the controller would be responsible for increasing the voltage to reach the required voltage and thus charge the batteries.

When we raise the voltage by a transformation process, there is always a decrease in the amount of electric current. Therefore, in times of lack of sunshine, the controller will ensure charging which, although it takes longer compared to times of sufficient sunshine, at least the load can be carried out.

Solar panels

A properly functioning photovoltaic energy system is composed of a set of photovoltaic modules and a set of complementary equipment, being batteries and charge controllers. These components may vary according to the methods used and the application of the PV system.

Photovoltaic modules generate electricity in direct current. Batteries store the electricity obtained from sunlight during the day, making it possible to recharge the batteries.

In the structure of the project there is a compass installed for better understanding and positioning of the same, regarding the direction of the sun's rays, seeking to improve the use of the sun's rays (geopositioning). Since the project and its use originate in Brazil, a country in the southern hemisphere, the modules have to be directed to geographic north, also known as true north, slightly divergent from the magnetic north of a common compass. This subtle repositioning provides greater efficiency in capturing solar radiation throughout the day. However, a greater inclination of photovoltaic modules to the North favors energy production in winter (when the apparent path of the Sun is facing North and lower than the zenith and the days are drier and clearer), while it hinders energy production during the summer (when the apparent path of the Sun is closer to the zenith and the days are cloudier and rainier). Therefore, it is of utmost importance that the inclination of the plates horizontally is made based on latitude, climatic aspects of the region of use and seasonal characteristics of energy consumption. For this reason, the angle of the solar plates in EcoQuad are adjustable. A rule of thumb is to tilt 5 to 25 degrees more than the local latitude, seeking to prioritize maximum energy production in the most critical month (ALVARENGA, 2006). The city of Rio Claro, in the interior of São Paulo, serves as the base for the car studies and, since it has a latitude of approximately 22ºS, we positioned the plates with an angulation of approximately 35º.

With the correct arrangement of solar modules, EcoQuad is able to absorb as much solar radiation as possible. As for its direction, the compass has the role of guiding the driver to position the car in the most correct and appropriate way possible, taking into account the physical provisions of where it is located.

For the project, two Kyocera brand boards were used, model KC125TM, which have a voltage of 18V and a power of 125W each. Although the plates described are relatively dated, their use is due to the disuse in which it was before the idealization of the project, which resulted in the reduction considered of the expected costs.

Engine

For the choice of the ideal electric motor, in a vehicle propulsion system, it is important that it has a high initial torque and can develop a final speed consistent with the characteristics defined for the vehicle, that is, when seeking to obtain a high torque, do not disregard the maximum intended speed (COSTA, 2009).

It was decided to use a permanent magnet motor for its simplicity of use and high torque capacity, in order to compensate for the choice of a stationary battery, which has low initial torque power (compared to Lithium). In addition to its high suitability for the project, this motor model is available for purchase over the internet or even in some industrial electronics junkyards. In this prototype, the working voltage is 36 Volts and the nominal power is 750 W, similar to those used in electric bicycles, widely spread in countries like China. The choice of a motor with a voltage of 36V is evident so that it could be powered by the solar plates in real time, without using the battery power itself, only when it was extremely necessary.

The motor chosen was a brushless type, whose power is 750W, its voltage is 36V and its rotation is evaluated at 500 RPM. After analyzing the EcoQuad system as a whole, it was realized that the most appropriate option would be to choose a motor suitable for bicycles, which is installed on the rim of one of the wheels. The motor also comes with accelerators, brakes and all the control system that a car needs.

Types of energy sources for the engine

When considering the prospects of today's world that insist on afflicting the environment - such as indirectly falling on the population and their quality of life - the construction of a car made mostly of unused parts, devoid of any source of fossil fuel and with a performance potential far superior to that of a conventional car, requires an energy source without any cost. If the EcoQuad were to use its solar modules to power the battery, which in turn would carry the load to the engine, then the cycle of using environmentally harmful materials would continue. This is due to the intensive use of the battery that would store all the load and participate in the process of large discharge during the movement of the car, drastically reducing its useful life. With the intensive use of the battery bank, its replacement would have to be done frequently, which would increase the maintenance cost of the EcoQuad, making it similar and expensive as a conventional car, in addition to causing serious damage to the environment by the disposal of batteries, which is mostly done improperly.

> *Improper disposal can cause the battery to deform in its capsule, which can lead to leakage of the toxic waste that is composed inside. The liquid inside the device is a non-biodegradable and non-decomposable product that causes pollution when it is discharged into subsoil, groundwater, rivers and waterways. Dangerous for hydrology and agriculture, causing irreparable damage to the environment and crops (ALVES DOS ANJOS, 2022).*

Due to these issues, the production and development of EcoQuad not only aims to use the solar plate to charge the batteries and drive the vehicle only by the latter, but also to use the solar plates as a primary source of energy.

The production of a motorized system with real-time power supply from the solar panels is the most suitable for this project. In this case, the battery continues its purpose of powering the EcoQuad. As will be analyzed later in this section, the EcoQuad needs an initial torque of which the solar panels cannot provide such energy and power in such a short period of time. Thus, when the use of solar panels as the main source of energy is required, the battery bank will provide energy for the initial torque, removing the EcoQuad from inertia and also at times when the irradiation is not sufficient to keep the EcoQuad in constant motion, such as in tree-lined streets. Should such a situation occur, the energy source will be immediately switched to the battery through the charge controller, specifically configured to perform the interconnection between the motor and its two possible energy sources.

In summary, EcoQuad offers two types of energy. The first and most conventional is the use of a battery bank as the sole energy source. The second is through the primary use of solar panels, which will be softly assisted by the batteries.

Calculations

Although it is possible to charge the battery bank in conventional sockets, the charge will be made only through solar radiation, so that the expenses for the operation of the car keep its purpose to be as low as possible, making it more affordable. In addition, with less excessive use of the battery, its useful life is increased, leading to its longer use and later replacement, making the car even cheaper.

In addition to calculating the efficiency that the modules are able to provide, it is necessary to find out the amount of energy generated by the solar modules, so that it is possible to infer the aptitude of the plates to provide enough energy in a certain period of time, so that the EcoQuad works continuously during this period, without losing its efficiency considerably at some point. Through these same calculations it will be possible to infer the motor's ability or lack thereof to drive the EcoQuad. In order to obtain such information, the insolation method was used to determine the amount of energy produced daily by the solar modules, in which the energy produced by the mode daily in Wh (*EP),* the daily insolation in Wh/m²/day (*ES*), the surface area of the module in m² (*AM*) and the efficiency of the module (*nM) are* used. No calculation was made specifically for the battery due to the knowledge of its nominal information, which certainly guarantees an efficient operation of the EcoQuad if used as the only energy source.

The quantification of energy provided by a photovoltaic system should be performed based on its month of lowest insolation, since otherwise, the results based on months of highest insolation would provide data that do not cover the whole year, causing the energy supply not to be guaranteed in all months. The average daily insolation rate per square meter in most Brazilian locations is 5000 Wh/m²/day. In the South of the country this number drops to 4500 Wh/m²/day and in the Northeast can reach more than 6000 Wh/m²/day (VILLALVA, 2012).

Equation (1)

$$EP = ES \,.\, AM \,.\, nM$$

When performing the calculation, the value of 7845 Wh is obtained, which if converted into joules is approximately $2.82.10^7$J in a whole day. Since the power is necessary to make a relationship with time, $2.82.10^7$ divided by $8.64.10^4$ seconds, it is concluded that the power supplied by the solar modules is approximately 325W.

In order to be able to use the EcoQuad through only spontaneous solar irradiation, the energy generated by the solar modules has to be minimally higher than the energy spent by the car. Using the kinetic energy equation, the total mass (m) of the EcoQuad was assumed to be 190Kg (60 Kg being the average total mass of the crew members in the tests performed) traveled at a speed (v) of 30Km/h (approximately 8.35 m/s).

Equation (2)

$$\frac{mV^2}{2} = \frac{190.(8{,}25)^2}{2} = 6624\,J$$

Thus, it is concluded that the EcoQuad, with a total weight of 190 kg and a speed of 30 km/h (8.35 m/s), needs approximately 6624 joules to start pulling.

By dividing the kinetic energy of the EcoQuad by the insolation power obtained, it is possible to infer that the time for the car to reach the expected speed and results would be 20 seconds.

Although this figure is significantly reduced by lowering the total weight of the EcoQuad or its expected speed, the design inter receive minimal assistance from the batteries that will provide the initial torque, while the solar plates effectively support the EcoQuad in motion.

Energy hybridization

The hybridization model of electric and solar photovoltaic energy presented in this project is innovative and designed for EcoQ system in the automobile market with an even greater advance compared to electric cars. Along with the new energy system, it is necessary to formulate a different type of vehicle to support the technology and attributes of the hybridization system, so EcoQuad has the potential to transform the transport sector with the replication of its energy system and the production of a simpler, lighter and more everyday type of vehicle.

Based on the theme presented, the hybridization system has as its principle the capture of solar energy so that it is directed to the the hybridization process, the bank could not be recharged when the EcoQuad was parked. Therefore, solar energy passes through the batteries, but in order to be used first and, when necessary, the engines will acquire a minimum amount of batteries, making the vehicle's autonomy always greater compared to just a common battery bank, used in electric cars, for example.

IV. RESULTS AND DISCUSSION OF RESULTS

In this chapter we present a complete analysis of the data obtained in tests to prove the functioning and efficiency of EcoQuad. It is also developed in this same section the approach of comparison topics between the EcoQuad and ordinary cars, designed mainly for short and daily routes, in order to show its relevance in current times and a better cost benefit to be explored by the population. Due to the different types of energy sources used, the tests were divided into two groups, which will be called "Sections" .

Section 1: battery bank

The tests were carried out in a multi-sports court with high exposure to sunlight and the objective was to measure the running time of the prototype in relation to different traction loads and the expected speed (30Km/h with a total crew mass of 170Kg). The energy source used in these experiments was from the fully charged battery bank, without the use of solar photovoltaic energy. These tests were also carried out to prove the ability of the battery bank to provide sufficient power to the engine and thus perform the movement. It should be noted that the same test was repeated several times in order to verify the veracity of the results obtained.

As previously mentioned, stationary batteries are characterized by being deep cycle, i.e.: they can be discharged without major loss of life. The tests done with only the use of the batteries did not exceed the safe discharge limit.

After each test, the batteries were properly recharged. In this way, the test period took around 15 days to be completely completed. It was decided to do only, for most of the analysis period, one test per day, in order not to change the characteristics of the battery or the way they could be recharged. In addition, in the tests of the batteries as a single source of energy, several tests were carried out in order to determine the autonomy of the EcoQuad in 4 types of load depth, being 100%, 80%, 60% and 20%.

In an attempt to simulate different masses of different conductors, the first phase of each test section was done with a 13-year-old 52 kg child who drove the prototype alone in a first stage. In the second phase of testing, two crew members were used, the 52Kg child from the first phase and an adult weighing approximately 80Kg. In the third test phase, two adults were used, one weighing approximately 90 kg and the other 80 kg.

According to the results obtained in the 15 days of tests, it was possible to build a graph illustrating the autonomy as a function of the mass pulled by the vehicle and the percentage of the loading depth. The masses described in the graph are not consistent with the tests performed as they were used to show a more accurate curve, instead of the large weight differences used in the analysis. Therefore, we performed the tests with the weights described above, identified the pattern of decrease and applied them to mass values closer to each other.

Assuming the driver uses the EcoQuad on a flat surface, it is possible to produce a projection of its range (Figure 2).

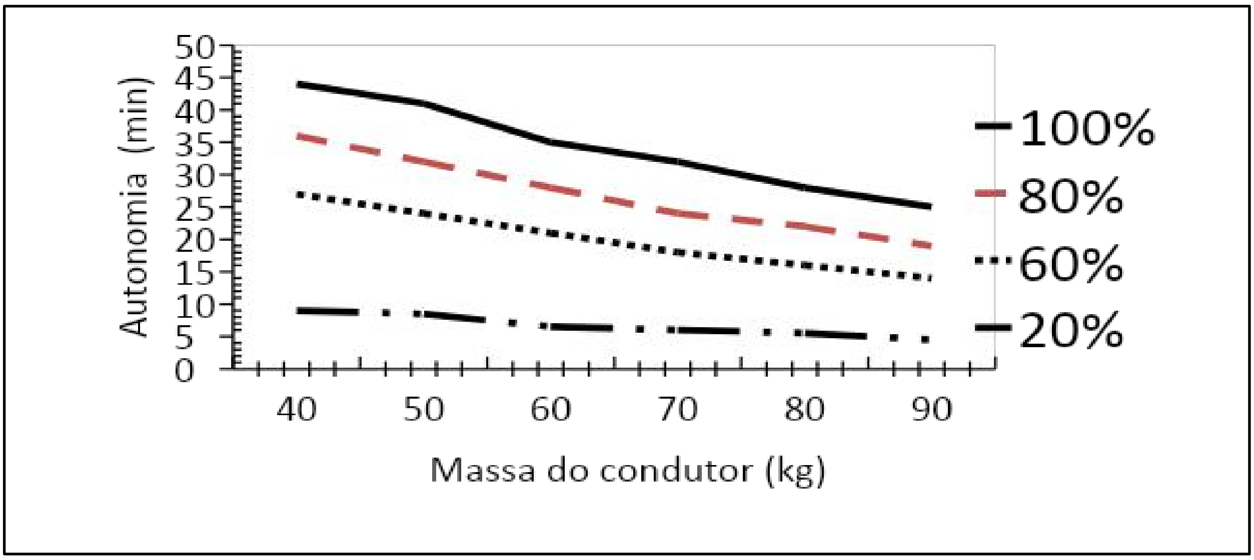

Fig.2 - Autonomy Versus Driver Mass

Assuming that the EcoQuad is used on a flat surface, it is possible to estimate a relationship between the distance traveled and the total mass of the driver (Figure 3).

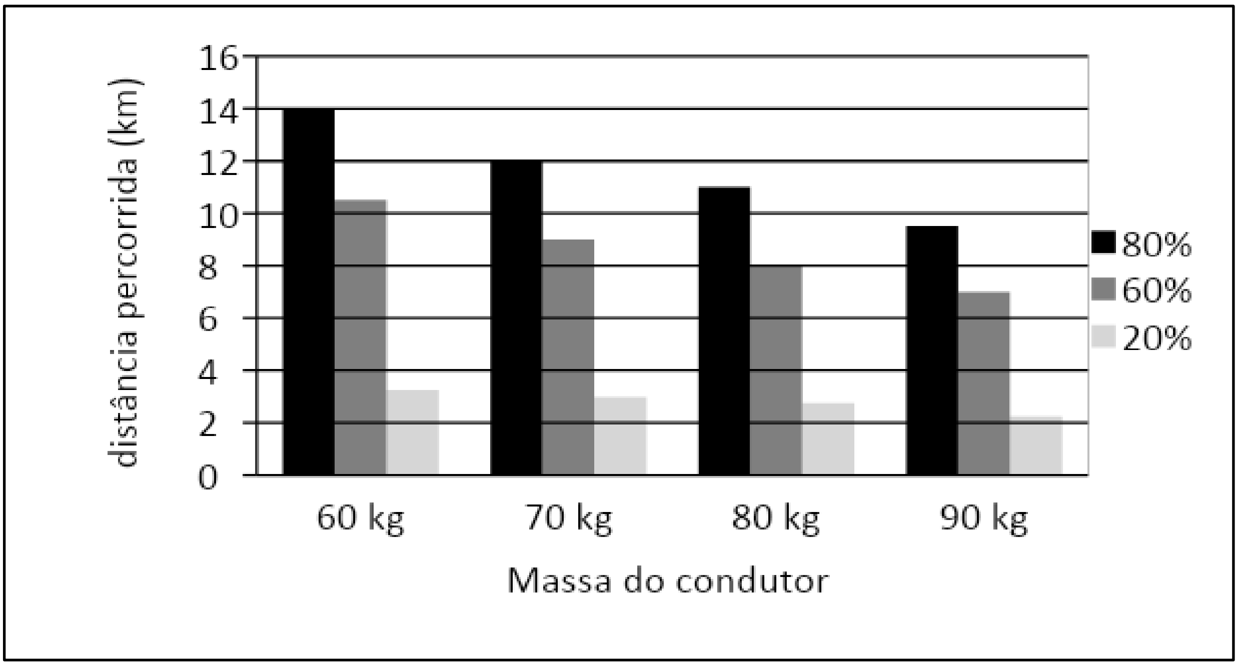

Fig.3 - Distance traveled versus conductor mass

Section 2: solar modules

The project had the pretext of building a vehicle totally free of any source of electricity and toxic to the environment, so it was thought only to use solar plates to drive the vehicle to drive at least one medium-sized adult. However, when analyzing the nominal specifications of the solar plate, it became clear that the total generated power of 325W of the plates would not be enough to perform the initial torque of the vehicle and also to drive it in areas of little insolation. Reservations are made if the total mass of the crew member is 52Kg and the period of use was close to noon. If the plates adopted to the project were more powerful, in addition to presenting greater efficiency, the proposal to only use solar plates could be considered. On ordinary streets, fast acceleration is required due to the constant traffic in cities. Therefore, as an example, if the EcoQuad stopped in front of a traffic light, it would not be able to keep up with the acceleration of other cars and get back into motion quickly, causing serious obstacles and possible traffic accidents.

After the testing period with batteries, tests were carried out using the energy coming from the solar modules in real time, in addition to being assisted by the batteries. This period lasted around 4 days. To perform the experiments, the structure of these analyses was schematized similar to that of the tests with batteries, being 3 phases with 52 Kg in the first, 132 Kg in the second and 170 Kg in the third. Due to the way solar modules work, the tests were not done considering the discharge percentage. It is not necessary to demonstrate the values obtained by means of graphs, since the autonomy would be basically unlimited, if there were not the small aids of the battery. Thus, the autonomy results using the hybrid configuration of electric energy and solar photovoltaic completely exceeded the metrics found during the tests using only the battery bank, thus becoming representative values because they do not match the daily use expected for this car, that is, less intense.

Project cost

EcoQuad's solar panels and bicycles were donated by Mariana de Almeida Castro, a businesswoman who sympathized with the project and had the initiative to contribute. The electric motor, the charge controller and all the components necessary for the distribution of energy to the motor were donated by the businessman Otto Wener Kuth, in order to help with the costs of the project. The three batteries were borrowed from an electronic platform system with a *nobreak* system from Colégio Puríssimo Coração de Maria, so that the tests could be carried out. The aluminum plates were found in a junkyard. Finally, the EcoQuad seats are donations from the advisor of this article, Professor Filippi Benevenuto Ongarelli, who took them from an Ultralight Flyer GT.

The following table describes each part used in the making of the EcoQuad and also the context of each material, together with its quantity and price.

Table 2 - Project cost

Devices	Quantity	Total Price
Solar plate (donation)	2 pcs.	R$800
Battery (borrowed)	3 pcs.	R$1410
Bicycle (donation)	2 pcs.	R$500
Engine, accelerator system (donation)	1 pcs.	R$2000
Parent company (donation)	1 pcs.	R$650
Aluminum sheets (found)	0,42 m²	R$30
Metal bars, welding and bolts	25 m	R$180
	Total	**R$5570**

Relevance of the project

Unlike other vehicles available on the market, EcoQuad is more attractive to the majority of the population by adapting and being developed based on the strengths of each of the modes of transportation evaluated in this project.

Firstly, EcoQuad addresses some of the difficulties faced when using electric scooters. However, although they have been gaining significant notoriety lately, the fact that they only hold one person and do not have the expected comfort during an average journey makes electric scooters potentially problematic in some situations, something that does not happen in EcoQuad, since it holds two passengers and has the comfort similar to that of a conventional car. Furthermore, based on the rate of motorcycle accidents and their resolutions, society is impacted by this data through a deep stigma regarding vehicles with only two wheels, which makes the EcoQuad and its four wheels even more attractive to the consumer market.

Another factor to be considered in transportation vehicles is the environment for which they were designed. The EcoQuad is intended to be used in a common lifestyle, which aligns with the daily priorities of the Brazilian population. In other words, the EcoQuad was developed based on average commutes such as from home to the owner's work, or to a local supermarket. Thus, smaller cities and, consequently, the interior, are the most suitable for the operation and efficiency of EcoQuad. However, this vehicle can be used perfectly in large cities with heavy traffic. This is due to the use of cycle paths, since their width is compatible with the width and size of the EcoQuad, in addition to being relatively far from other cars, which reduces the possibility of accidents.

EcoQuad's main goal is to promote a new style of energy to be used by large automotive companies, based on the intelligent hybridization between solar energy and electric energy only when needed. This new energy configuration provides the most sustainable model among all those already present in the market, being: fossil fuels, fossil fuels and electric energy and electric energy only. If compared to the first two models, EcoQuad presents clearly more positive results in favor of the reduction of polluting gases, but when compared to electric cars, its differential turns out to be slightly more specific. Currently, electric cars are considered the best and least polluting means of transportation on the market. However, if we conduct a long-term study, it is realized that batteries as the only source of energy for these cars, their use ends up being extreme and very harmful, which ends up leading to a relatively frequent maintenance and potentially irregular disposal of batteries, generating serious damage to the environment. The EcoQuad, on the other hand, uses mainly solar energy and leaves its source of electricity only for more specific situations, so as not to demand excessively from the batteries, extending its useful life and making its maintenance much later compared to that of an electric car.

Finally, although it is possible and even foreseen for the EcoQuad batteries to be recharged through solar energy, their charging through domestic electricity still proved to be cheaper than a popular car. When performing the tests described above, we realized that charging the EcoQuad using sockets cost approximately R$1.50 (R$0.50/KWh) after traveling 14Km. After collecting this data, we calculated how much it cost to fuel a Volkswagen Up! after traveling the same 14Km, which ended up resulting in R$4.50, since it travels on average 12Km / L of Ethanol. Therefore, recharging the EcoQuad is up to 200% cheaper compared to refueling a popular car.

V. FINAL RESULT

The vehicle was built and successfully put into operation. Figure 4 shows the finished vehicle and figure 5 a test in the courtyard of Colégio Puríssimo, together with high school students.

Fig.4 - Final result of EcoQuad

Fig.5 - Final result of EcoQuad - Walking in the courtyard of Colégio PUríssimo

The project was presented at the Brazilian Science and Engineering Fair (FEBRACE) in 2023, winning 1st place in the Engineering category and 4th place overall in the largest Science and Engineering Fair in

Latin America. Figure 6 depicts the moment when the medals were awarded to the group.

Fig.6 - Awards – FEBRACE

VI. CONCLUSIONS

In view of all the experiments, tests and analyzes carried out, the efficiency of EcoQuad is proven, which through improvements and the use of more suitable parts can be further improved. The problems mentioned at the beginning of this article, currently responsible for the high emission of harmful gases to the environment and the lack of accessibility of more ecological products due to their prices are partly solved with the introduction and propagation of this vehicle. Although there is no evidence to prove such improvements, the objective of the work in disseminating the construction of a more affordable, higher performance and more environmentally friendly vehicle than ordinary cars and even electric cars has been achieved. EcoQuad has achieved the expected results and aims to contribute to the automotive industry.

The goal of producing a vehicle like the EcoQuad was never to revolutionize the automotive market in a way that could be replicated on a large scale for the population. Its real purpose is to prove greater accessibility, efficiency and sustainability through the use of solar photovoltaic and electric energy together, working mutually with each other, as is described in the title of this project. Current electric cars use only batteries, which promotes much greater wear and tear, leading to a drop in efficiency gradually and a more advanced replacement, costing a lot of money and damage to the environment. In the future, companies are expected to produce simpler, more efficient cars with solar panels, so that the mutualistic relationship between batteries and solar modules reaches a balance between efficiency and clean energy consumption, as demonstrated in the construction of EcoQuad.

With the arrival of the electric car and even electric and solar hybrids, there will be extremely positive transformations in the transport, economic and social sectors. However, these transformations will bring about changes and obstacles with which people will have to adapt. In addition, with positive developments there will always be negative aspects. It is up to us to find solutions to these obstacles and thus evolve technologically and as a society.

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